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**Statement of**
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**before the**

**Subcommittee on Space and Aeronautics**
**Committee on Science and Technology**
**U.S. House of Representatives**

Chairwoman Giffords and Members of the Subcommittee, thank you for the opportunity to appear today to discuss NASA's next-generation human spaceflight program and the Agency's emphasis on continuing to improve safety factors for our most valuable assets – the men and women who dare to explore the mysteries of our universe. Everyone at NASA is dedicated to ensuring that these brave pioneers are equipped to safely conduct the missions asked of them, and that they are then able to safely return home to their loved ones. Simply put, safety is the first of our core values at NASA, and it is also the top priority of the Agency's Constellation Program.

As requested in your invitation to me to testify at today's hearing, my testimony will outline NASA's ongoing focus on safety matters with regard to human spaceflight, focusing primarily on how the Agency sought to improve crew safety for the Constellation Program above that achieved on previous crewed spacecraft. This has been accomplished by incorporating safety in all aspects of Constellation from the beginning of the design process. My testimony will also outline how the Constellation Program has progressed into the early developmental testing stages, and how data from those tests is being used to improve our models and to validate the rigorous safety requirements developed for the Constellation vehicles.

## Columbia Accident Investigation Board and the Exploration Systems Architecture Study

In 2003, the Columbia Accident Investigation Board (CAIB) report provided NASA with guidelines for moving forward with our return to flight efforts. In addition to determining the causes of the Columbia accident, the CAIB also provided the Agency with a set of comprehensive recommendations to improve the safety of the Space Shuttle Program and to change the corporate culture of the Agency – changes that have positively impacted the Constellation Program. NASA has also established processes that enhance our ability to assess risk and to improve communication across all levels and organizations within the Constellation team.

More specifically, with regard to the design of the next-generation crew launch vehicle, the CAIB recommended that:

> *"The design of the system [that replaces the Shuttle] should give overriding priority to crew safety, rather than trade safety against other performance criteria, such as low cost and reusability, or against advanced space operation capabilities other than crew transfer."*

In other words, the CAIB gave NASA clear guidance that the next-generation crew launch vehicle should be simpler and safer, and that crew safety should be the driving design principle. Now the question became, how did we meet this challenge? More specifically, how did we make a vehicle "inherently safe" while also protecting against residual risk, in a mass-constrained, highly-energetic system such as a launch vehicle? We started by going back to the basics, first identifying the known risks and hazards and then working to eliminate, or at least to minimize, each one of them. From there, the designers turned their attention to developing acceptable mitigation approaches for the residual risks. From the beginning, this complicated and lengthy process, known as risk-informed design, has been at the heart of NASA's Constellation Program.

However, before there was even a program known as Constellation, NASA used the CAIB guidance and other policy directives to initiate the Exploration Systems Architecture Study (ESAS) in 2005 with the purpose of assessing and defining the top-level requirements and configurations for crew and cargo launch systems, not only to support future lunar and Mars exploration programs, but also to support the International Space Station.

In conducting its review, the ESAS team focused on guidance issued by the Chief of the Astronaut Office in May 2004 – particularly on one key statement, which states:

> *The Astronaut Office believes that an order-of-magnitude reduction in the risk of loss of human life during ascent, compared to the Space Shuttle, is both achievable with current technology and consistent with NASA's focus on steadily improving rocket reliability, and should therefore represent a minimum safety benchmark for future systems. This corresponds to a predicted ascent reliability of at least 0.999.*

Keeping in mind the CAIB recommendation of focusing on crew safety first, ESAS placed a premium on crew safety. All candidate crew launch vehicle concepts considered during ESAS included an escape capability referenced as a launch abort system or LAS. During the study, NASA eliminated any launch vehicle concept that did not approach at least a predicted probability for loss of crew (LOC) of 1 in 1,000 missions. In addition, concepts that would place the crew module in close proximity to the boosters and/or other potential sources of accident initiation were eliminated to improve the reliability of a LAS and to improve the likelihood of crew survival in the event of an accident during ascent. This process resulted in the selection of the single solid First Stage concept, which would later become known as the Ares I Crew Launch Vehicle. In the end, the potential for increased safety provided by Ares I (compared to other alternatives considered during ESAS) was based primarily on the simplicity of the First Stage.

As compared to the Space Shuttle, the Ares I will be a simpler vehicle to process prior to launch because NASA has designed the Ares I to have fewer moving parts, thus requiring less hands-on labor prior to launch, and also reducing the potential for human error. In addition to the inherent safety associated with the rocket's simplified design, the Ares I integrated rocket will have a LAS for crew, as will be outlined in greater detail during the next section of this testimony.

## The Constellation Program and Risk-Informed Design

In the Apollo era, crewed launchers were designed with the best level of expertise available, tested to exhaustion, and then robustness or redundancy was added to mitigate the residual risk. The goal was to make the design as reliable as possible, so that backup systems would never have to be used, and to make the backup systems as robust as possible to maximize the likelihood of crew survival and return, should a failure (anticipated or not) of the primary system or element take place. This approach worked, producing dramatic advances in reliability and crew safety, as proven, for example, when the Lunar Module did not experience a single anomaly on the final lunar mission, and the crew survived despite the explosion aboard the Command/Service Module during the Apollo 13 mission. However, as my colleague, Bryan O'Connor, will outline in his testimony, safety at NASA is also about more than design. NASA's focus on safety also includes ensuring that our crews and operators know how to deal with contingencies, and that, when someone has a concern about a safety issue, whether it be a crew member, a design team member etc. that there are clear paths for those who have dissenting opinions to raise their concerns to senior management.

Today, NASA's Constellation Program has a goal of increasing astronaut safety tenfold relative to Shuttle missions. While a seemingly daunting challenge, NASA believes that this goal is achievable for many reasons.

First, NASA is utilizing a multi-faceted design objective for safety that remains the same as during the Apollo era -- design the system to be as inherently safe as we can make it, and then add backup to mitigate the predicted as well as unknown residual risk. This, along with aforementioned guidance issued by the Chief of the Astronaut Office in May 2004, was the starting point of the Constellation design team. As has been stated, inherent safety implies the elimination of hazards that have historically been associated with the operation of the type of system being designed. This, in turn, implies the systematic identification of the hazards associated with operation of the system alternatives being considered.

The key to a risk-informed design is integrating risk analysis into the design alternative evaluation and selection process in a fundamental way by using newly capable, logical, and phenomenological (or physics-based) computer models. These models help focus the design effort toward identifying and reducing or eliminating design hazards, which, in turn, helps NASA identify and develop mitigation approaches to address the residual risks. In addition, NASA recognizes that safety of an overall system can be improved by addressing human factors issues, which is why the Ares I Upper Stage and Orion designs have been developed to simplify and automate processing and operations as much as possible, thus reducing the potential for human error.

Second, unlike the Space Shuttle, the Orion crew capsule will have a LAS that will offer a safer and more reliable method of moving the entire crew out of danger in the event of an emergency on the launch pad or during the climb to Earth orbit. Mounted at the top of the Orion and Ares I launch vehicle stack, LAS will be capable of automatically separating the Orion from the launch vehicles and positioning the Orion and its crew for landing. In comparison, during Apollo, NASA had comparatively little experience and computational capability, and the abort effectiveness was estimated by comparison to escapes from high-performance military aircraft combined with the results of a few escape system tests. Today, with the flight tests combined with advanced simulation tools and advanced computers available, NASA can conduct a more thorough analysis. Specifically, the integrated abort system's effectiveness can now be calculated using computer models of the blast environment by employing more realistic, physics-based, simulations of abort conditions. While computer models and computational capability were much less capable during the Apollo era, today this calculation can be carried out with remarkable speed and accuracy given NASA's evolved engineering expertise and the computational power of our computers.

Third, Constellation has chosen to tightly interweave the design and safety team members into the decision making process. As a result, the Constellation team represents skills from safety and reliability engineering disciplines traditionally found under the Safety and Mission Assurance organizations, as well as engineers with backgrounds such as computational fluid dynamics, aerospace, and physics disciplines. The team has been given the clear direction to work daily with the design engineers to provide expertise and feedback via various assessments and analysis techniques throughout the design maturation process. This investment demonstrates a sincere commitment to the CAIB findings.

Finally, as a key element of our risk-informed design process, the Agency has an active risk-management process that identifies technical challenges early in the process and aggressively works solutions. The Program identified key risks during the risk management process and associated mitigation steps to inform the designs. Technical risks are identified by likelihood of occurrence and consequence. For example, NASA is currently working a thrust oscillation risk for the Ares I First Stage. This phenomenon is a characteristic of all solid rocket motors. NASA has made significant progress in identifying both primary and backup approaches to mitigate the oscillation effect, and we now believe that we have now baselined a passive mitigation technique. However, additional testing will continue to ensure we have the best mitigation prior to making the final decision at the Constellation Program's Preliminary Design Review (PDR) early next year. With regard to the Upper Stage, the J-2X engine remains a priority, with the focus being on achieving needed performance requirements while also incorporating modern approaches (e.g., materials, manufacturing, electronics, etc) into this Apollo-era heritage hardware.

In choosing a Shuttle-derived architecture, NASA recognized from the outset that some of the heritage hardware would need to be modified or replaced so as to achieve improved safety, reliability, as well as to meet needed performance and lower lifecycle costs. At the same time, the Agency recognized that leveraging systems with human-rated heritage would reduce the uncertainties and risks associated with developing a new human-rated crew launch vehicle. For example, the Ares I First Stage consists of a five-segment reusable solid rocket motor (RSRM), an aft skirt, a forward skirt, and a frustum. The five-segment RSRM is an evolutionary development from the four-segment solid RSRM strap-ons currently utilized to power the Space Shuttle. As a result, the Constellation Program is building on the proven track record of this heritage hardware. There have been 252 solids flown in the Shuttle Program with one failure (Challenger STS-51L). The Ares I also benefits from the improvements in the RSRMs that have resulted from recovery and post-flight inspections along with modifications that have been made to the Shuttle boosters. The Ares I booster also will continue the protocol of recovery and post-flight inspection that began in the Shuttle Program.

The J-2X engine would be used for both the Ares I and Ares V vehicles, thus creating a common link between the two vehicles that is based on evolved heritage hardware, specifically the powerful J-2 engine that propelled the Apollo-era Upper Stage on the Saturn I-B and Saturn V rockets, and the J-2S that was developed and tested in the early 1970s. In addition, the J-2X will leverage knowledge from the Delta IV's RS-68 by incorporating manufacturing techniques from the RS-68 into the J-2X engine. However, NASA recognizes that there are also challenges involved with utilizing and integrating heritage systems into new vehicles, so for the J-2X, NASA has taken steps to increase the amount of component-level testing, to procure additional development hardware, and to work to make a third test stand available to the contractor earlier than originally planned.

Already, the Ares I risk assessment and failure analysis teams have provided input and/or impacted the outcome of Ares I design issues, trades, or risks on numerous challenges, including:

- Abort triggers study: Provided LOC and Abort Effectiveness assessments, including engineering models and timing, to determine what potentially catastrophic scenarios warrant abort sensors and software algorithms;

- Separation study (booster deceleration motors ): Hazard analysis combined with probabilistic design analysis led to the design decision to increase the number of booster deceleration motors from eight to 10; and,
- The Hazards Team identified that the First Stage and Upper Stage designs failed to meet properly at the interface flange (due to differing number of bolts) and a re-design was instituted. The team provided an assessment to Upper Stage that resulted in clocking of the hydrogen and oxygen vents to improve separation distance.

While NASA awaits further direction from the President and Congress with regard to the future of human spaceflight, the Agency is continuing to pursue our current programs, per direction from the Office of Science and Technology Policy. Currently, the Constellation Program is progressing through an active phase of hardware and software tests and, as tests are completed and data analyzed, our models will be updated, allowing us to improve safety and improve systems performance. At the same time, we are investing heavily in risk-reduction hardware and activities that will help calibrate and refine our models and simulations related to the Ares I and Orion – data that is essential to incorporate as early as possible into vehicle designs, based on the Program's risk-based design approach. NASA is developing an Integrated Test and Verification plan that includes a series of developmental tests to further refine and validate our designs. Test flights, for example, are being designed to include several hundred measurement points that will characterize the actual operating environment and system performance in the most stressing of cases. NASA is in the process of continuing to refine this test and verification strategy prior to the Program's PDR early next year, when the Integrated Test and Verification plan will be baselined.

Following are just a few examples of recent and upcoming developmental tests which have yielded, or are expected to yield, significant amounts of data that will be incorporated into our risk-based design effort:

- In September 2009, NASA and ATK conducted the first test of the Ares I's five-segment development motor in Promontory, Utah. This test provided NASA with valuable thrust, roll-control, acoustics and vibration data as engineers continue to design the Ares I. In all, seven ground tests are scheduled for the five-segment booster.
- In October 2009, the Ares I-X test flight took place at Kennedy Space Center in Florida. Although data is still being collected and processed from more than 700 on-board sensors, preliminary results show that the vehicle performed precisely as it was meant to perform. Early data shows that the vehicle was effectively controlled and stable in flight. Thrust oscillation frequencies and magnitude data from the Ares I-X flight are consistent with measurements from recent Shuttle flights that were instrumented, leading us to conclude that the oscillation vibration on the Ares I would be within the bounds that the Ares I is currently being designed to. When assessment of this data is finalized, we believe it will provide tremendous insight into the aerodynamic, acoustic, structural, vibration, and thermal forces that Ares I is expected to experience -- knowledge that will contribute substantially to the reliability and safety of the Ares I design, as well as to enhancing NASA's modeling capabilities for future vehicles.
- In March 2010, NASA plans to perform its first developmental test of the Orion LAS at the White Sands Missile Range, New Mexico. This test will validate the LAS design approach and will contribute substantially to the Orion's final designs for reliability and safety. NASA plans a series of tests to characterize the LAS. The Pad Abort I test is the first of these tests, and it will address what happens if an emergency occurs while the Orion and the launch vehicle are still on the launch pad. Other tests will determine how the LAS performs in critical parts of the flight regime.

**Human Rating and the Constellation Vehicles**

The launch of any spacecraft is a very dynamic event that requires a tremendous amount of energy to accelerate to orbital velocities in a matter of minutes. There also is significant inherent risk that exposes a flight crew to potential hazards that could be catastrophic, if not controlled. Therefore, through a very stringent process of human rating, NASA attempts to eliminate hazards that could harm the crew, control the hazards that do remain, train the crews and operators to react appropriately, control the manufacturing and test of all components to minimize errors, and provide for crew survival even in the presence of system failures. Spaceflight vehicles are cleared by NASA to carry crew for missions that are associated with specific mission and performance requirements in an engineering flight test environment. It is also important to note that certification is made for an entire spaceflight system (i.e. Ares I, Orion, and associated ground support infrastructure count as one entire system), and not for specific elements of a system. NASA is currently in the process of developing those specific mission requirements for Ares I and Orion.

To guide the evolution of human rating requirements for any mission, NASA is developing Agency-level requirements documents. However, human rating a spaceflight system is not as easy as following one document. Instead, it is an intricate, continuing process, involving the translation of requirements into designs that can be built, tested, and certified for flight, and an understanding of risks with mitigation approaches in place. However, the challenge to projects such as Ares I and Orion is that there is no single document that spells out what they should do to receive a human rating certification from the Agency.

NASA is investing FY 2009 Recovery Act funds to begin development of a more concise set of NASA human rating technical requirements. These requirements would be applicable to NASA developed crew transportation systems as well as commercially-developed crew transportation systems for use by NASA. This task is being performed by a team comprised of representatives from NASA's human spaceflight programs, the Astronaut Office, Agency technical authorities, including the Office of Safety and Mission Assurance. We are also consulting with other Government partners such as the Federal Aviation Administration and with commercial stakeholders.

**Conclusion**

In closing, I would like to quote from the October 2009 Review of U.S. Human Spaceflight Plans report: "Human space travel has many benefits, but it is an inherently dangerous behavior." NASA wholeheartedly endorses this statement because it is a challenge we live with day in and day out. Safety is and will always be our number one priority in everything we do. That is why the Constellation Program has employed a continuous risk-informed design process, and that is why our designs are being developed with an overriding priority given to crew safety at every stage of the design and operational process.

Chairwoman Giffords, I would be pleased to respond to any questions that you or the other Members of the Subcommittee may have.